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(54) Title: CELL GRANT MECHANISM

(57) Abstract

A cell grant mechanism is presented which allows a central device (110) to control the transmission of cells from one or more remote devices (140) connected to the central device (110) over a physical medium. Grants are issued from a grant table (700) in the central device (110) to allow the remote devices (140) to transmit cells to the central device (110). The spacing of the grants are optimized to minimize cell delay variation. When there are unused cell opportunities, central device (110) can issue grants to devices (140) to utilize the unused cell opportunities on an available bit rate basis.

TITLE

Cell grant mechanism

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Field Of The Invention

The field of the invention is telecommunications, and
more specifically, the use of Asynchronous Transfer Mode
(ATM) technology to transport cell based information over a
physical medium (layer) in which a single network point
connects to one or more devices over a bi-directional
communications network. The invention specifically relates
to when devices on the ATM network are allowed to transmit
data, so that best utilization of the communications
resources (bandwidth) is made.

Background Of The Invention

In ATM distribution systems, the physical layer is
defined as a functional group comprised of hardware,
software and transmission media which converts an ATM cell
stream into bits to be transported over the transmission
media. The physical layer supports the transmission and
reception of these bits. Examples of transmission media are
optical fiber, coaxial cable, free space, and twisted copper
pairs.

In many cases the network is configured in a point-to-
multipoint or bus configuration on a shared media, where
several devices receive from and transmit to a single
station. Examples of a shared media include free space

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propagation such as in radio systems, where a base station communicates with a number of remote stations, or a computing network in a small business in which all of the terminals are connected to a central server by a single pair
5   of wires running throughout the building.

ATM networks transfer information in the form of cells. These cells contain both a data field and a header field. The data field contains user data, while the header field contains routing/identification and error control fields.
10   Packet based networks transmit information in the form of packets which have similar structures to the cells in ATM networks. When used herein, the term cell refers to any type of cell or packet in a communications network.

In cell based networks, devices are granted permission
15   to transmit one or more cells from a buffer which contains cells awaiting transmission. The permission can be in the form of a grant, which allows the device to transmit a cell in an upcoming opportunity. The term cell opportunity, when used herein, refers to an allocation of time or frequency
20   which can be used to transmit a cell. For networks which are based on a form of time division multiplexing or time division multiple access, a grant can be received in a frame which indicates that a cell opportunity in a subsequent frame can be used.
25   In an ATM network, connections are established between devices on that network and are termed Virtual Circuits (VCs). The virtual circuits have parameters associated with them which indicate the data rate the virtual circuit provides and the type of service. The type of services
30   which can be provided include Constant Bit Rate (CBR), Variable Bit Rate (VBR) or Available Bit Rate (ABR) transport on a virtual circuit. These virtual circuits can exist between devices on the shared media and a central receiving point, as well as on point-to-point connections.
35   When a virtual circuit is established between two points in an ATM network, there are characteristics which

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are associated with that virtual circuit.   One
characteristic is the data rate for the virtual circuit.
The data rate for the virtual circuit will establish how
frequently cells are transmitted.

5   Simultaneously with the development of ATM technology,
there have been advances in Fiber-to-the-Curb (FTTC)
technology in which devices are connected to the telephone
central office via a network of optical fibers connecting
the central office to single network points called Optical
10   Network Units (ONUs) which in turn connect to the subscriber
residence via a coaxial cable, and to the devices in the
residence via a passive splitter and in-home coaxial wiring.
In these FTTC networks, signals can be routed to the
residence via a single coaxial cable connecting the
15   residence to the ONU, but the passive network in the home
results in a shared media, with all of the devices in the
residence needing to transmit over a single coaxial cable.

         One of the goals of the present invention is to provide
one or more embodiments which permit the transport of ATM
20   cells over a point-to-point and point-to-multipoint networks
in a manner such that devices on that network are issued
grants to transmit cells to the ONU, and that these grants
are allocated in a manner that guarantees that the virtual
circuits that have been established between the central
25   station and the devices have the Constant Bit Rate (CBR),
Variable Bit Rate (VBR) or Available Bit Rate (ABR) services
that they have contracted for in the system, according to
the parameters specified in the Quality of Service (QoS)
associated with each of the virtual circuits.   The QoS
30   defines the basic parameters of the VC including the cell
loss rate and average delay.

         Another goal of the invention is to provide a method
for issuing grants such that cells associated with CBR
services have a minimum variation between cells, resulting
35   in a low Cell Delay Variation (CDV).

These and other features and objects of the invention
will be more fully understood from the following detailed
description of the preferred embodiments which should be
read in light of the accompanying drawings.

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Summary Of The Invention

A method for allocating bandwidth in a cell based
communications system is presented in which a grant table is
constructed which contains grants to allow one or more
10   remote devices connected to a central device to transmit
cells. The number of grants required for a particular
device and VC is calculated and the optimum locations for
those grants in the grant table are calculated. The optimum
locations are those locations which space the grants evenly
15   and minimize cell delay variation.

In the event that grants already exist in the desired
locations, an offset is applied to the desired locations and
alternate locations which minimize cell delay variation are
calculated.

20   Devices that have information which can be transmitted
on an ABR virtual circuit transmit the number of cells they
have awaiting transmission to the central location which
maintains that information in a queue table. When the
central device has one or more locations in the grant table
25   which are unused, remote devices having cells awaiting
transmission are issued grants. This is accomplished by
examining the queue table and determining that a device has
one or more cells awaiting transmission and issuing that
device one or more grants. In the event that there are
30   multiple devices communicating with the central device, the
queue tables for each device are examined sequentially to
determine if there are cells awaiting transmission and to
issue grants to those devices.

The central device can also be connected to a master
35   device which may not have the bandwidth to accommodate all
of the cells being transmitted from the devices to the

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central device and which will be subsequently transmitted to
the master device. A signal can be issued from the master
device to the central device which prohibits the further
issuance of ABR grants to the devices connected to the

5 central device and which therefore prevents the overflow of
memories or First-In-First-Out registers in the master
device.

Brief Description Of The Drawings

10   The accompanying drawings, which are incorporated in
and form a part of the specification, illustrate the
embodiments of the present invention and, together with the
description serve to explain the principles of the
invention.

15   In the drawings:

FIG. 1 shows a Fiber-to-the-Curb network with a point-
to-multipoint coaxial network connecting the Optical Network
Unit (ONU) with devices in the residence.

FIG. 2 shows a grant table.

20   FIG. 3 illustrates a method of allocating grants for
constant bit rate (CBR) and variable bit rate (VBR) services

FIG. 4 illustrates a method of allocating grants for
constant bit rate (CBR) and variable bit rate (VBR) services
using an offset in the cell requests.

25   FIG. 5 illustrates a method of generating grants for
available bit rate (ABR) services.

FIG. 6 illustrates an algorithm for grant location
optimization.

FIG. 7 illustrates an algorithm for the allocation of

30 ABR grants.

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Detailed Description

Of The Preferred Embodiment

In describing a preferred embodiment of the invention
5   illustrated in the drawings, specific terminology will be
used for the sake of clarity. However, the invention is not
intended to be limited to the specific terms so selected,
and it is to be understood that each specific term includes
all technical equivalents which operate in a similar manner
10   to accomplish a similar purpose.

One embodiment of the present invention is directed to
a method of allocating bandwidth to devices on a point-to-
multipoint or shared media, such that different types of
services including CBR, VBR and ABR can be provided, and
15   that CBR and VBR services have a minimum of CDV.

To allow the various types of services, including CBR,
VBR, and ABR services, to be transmitted upstream over a
shared media, a grant table is utilized in the central
receiving point (ONU). The grant table issues grants to the
20   devices so that they can transmit their upstream cells. The
grant table is composed of memory which contains the
identification (ID) number of the device which is being
granted permission to transmit a cell during any given
transmission opportunity. The grant table is read
25   continuously, and the device IDs form grants which are
transmitted in the downstream (ONU to device) direction. The
devices, upon observing grants containing their IDs, will
transmit a cell to the central receiving point (ONU).

The grant table can be constructed by utilizing the
30   peak cell rate (PCR) value for the CBR and VBR virtual
circuits associated with a device, and the minimum cell rate
(MCR) for ABR virtual circuits associated with that device.
The grant table can be programmed such that devices which
need CBR and VBR services periodically receive grants to
35   maintain the PCR, and that variation between the grants is

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minimized. This results in CBR and VBR services with a
minimum of CDV.

The grants that are available after PCR and MCR
requirements have been met can be used for ABR virtual

5   circuits by issuing these grants to devices which have
indicated that they have cells stored and ready to be
transmitted. The mechanism in which available grants are
allocated consists of monitoring the number of cells each
device has stored for transmission, and keeping this

10   information in a queue table at the central receiving point
(ONU). If there are cells ready for transmission from the
devices, the grant table will indicate so, and an ABR grant
generator uses this information to determine which device
should be issued a grant. In this way grants not needed for

15   CBR and VBR services are used for ABR services, and the
capacity of the channel is used to the fullest extent
possible.

One embodiment of the invention is its use on a FTTC
network in which the coaxial drop cable from a central

20   receiving unit is connected to a number of devices in a
residence. The grant table is located in the central
receiving unit, and grants are issued to the devices in the
residence such that the QoS for Virtual circuits from the
device to the central receiving unit are maintained.

25   FIG. 1 illustrates a Fiber-to-the-Curb (FTTC) network
which delivers telecommunications services to a residence
250. Services are provided in the FTTC network shown in
FIG. 1 via a Host Digital Terminal 100 which is connected to
an Optical Network Unit 110 via an optical fiber 200. The

30   connection to the residence 250 is made by a ONU physical
layer transceiver 120 which is connected by a coaxial drop
cable 210 to a splitter 220 which is connected to one or
more devices 140 via in-home coaxial cable 230. One or more
residences can be served by ONU 110. In a preferred

35   embodiment eight residences 250 are served by ONU 110.

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Although the preferred embodiment utilizes a coaxial drop cable 210, a number of alternate media can be used to connect ONU 110 with residence 250. This includes wireless transmission and transmission over twisted pair.

5   Transmission media and techniques for this connection are well understood by those skilled in the art. Similarly, the transmission media in the residence 250 is not limited to coaxial cable.

In the FTTC system digital signals are used to carry voice, video, and data signals to the devices. Asynchronous

10   Transfer Mode (ATM) protocols and formats can be used to carry the signals. The system requires bi-directional communications between the devices in the residence 250 and the ONU 110. Information is transmitted in the upstream

15   direction, for example, from the devices 140 to the ONU 240. Via the Universal Test & Operations PHY Interface for ATM (UTOPIA) interface 310, the devices 140 can be connected to a number of types of terminal equipment including televisions, telephones, and computers.

20   The system provides for the transport of ATM cells in the upstream direction as well as the downstream (ONU to devices) direction. The relevant interfaces for this network are illustrated in FIG. 1 and are the User Network Interface (UNI) interface 300 on the coaxial cable and the UTOPIA

25   interface 310 at the output of the device.

The devices in the residence 250 are connected to ONU physical layer transceiver 120 via a subscriber coaxial cable network, which when used herein, is defined as a network comprised of a coaxial drop cable 210, splitter 220,

30   and in-home coaxial wiring 230, which connects an individual residence 250 to the ONU physical layer transceiver 120. Use of the term subscriber indicates that the customer in the residence is a subscriber or potential subscriber to the services provided over the FTTC telecommunications network.

35   The subscriber coaxial cable network forms a shared media since it allows all devices 140 connected to it to access

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the ONU physical layer transceiver 120 with no active switching.

Since the subscriber coaxial cable network forms a shared media, a multiple access protocol is required to
5 permit the devices 140 connected to the subscriber coaxial network access the ONU physical layer transceiver 120.

A number of multiple access protocols can be used including Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA) and Time Division Multiple
10 Access (TDMA). When a TDMA protocol is used the devices will be assigned opportunities for the transmissions to the ONU physical layer transceiver 120, and, when ATM protocols are used, will transmit one or more cells in the opportunities. The TDMA protocol requires that the devices
15 140 transmit cells in a manner such that the data arriving at the ONU physical layer transceiver 120 from the devices 140 does not overlap in time. The TDMA technique is well understood by those skilled in the art.

A mechanism used to allow devices 140 to communicate
20 with the ONU 110 by utilizing opportunities is a grant table 700 which is illustrated in FIG. 2. In a preferred embodiment the grant table 700 is located in ONU 110. The grant table 700 is composed of a grant table memory 510 and an address decoder 500. The address inputs 505 are stepped
25 through such that the contents of the grant table memory 510 are read sequentially from the memory and appears at data outputs 515.

Grants for each device must be made at a rate which corresponds to the negotiated Quality of Service (QoS) for
30 each virtual circuit connected to that device. Based on call connection requests, a number of virtual circuits are established over time which each have defined peak cell rates (PCRs) and sustained cell rates (SCRs) in both the upstream and downstream directions. Virtual circuits
35 established for ABR (available bit rate) services may also include a minimum cell rate (MCR). Grants must be provided

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to each device at a rate high enough to accommodate the aggregate QoS requirements for all of the upstream virtual circuits from a given device.

Even though a given VBR virtual circuit will only
5   output cells at its SCR over the long term, it is capable of outputting cells at its PCR over the short term. Since the ONU 110 cannot anticipate when this will occur, it must allocate grants for each VBR virtual circuit at the PCR - otherwise the virtual circuit would not be provided the
10   negotiated QoS. Given that grants for each VBR virtual circuit must be generated at the PCR, the aggregate PCR for a device can be calculated by summing the PCRs for all of the CBR and VBR virtual circuits. To this aggregate must be added the MCR of all ABR virtual circuits, thus
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$$PCR_{device} = \sum_{i=0}^{n} PCR_{non-ABR\ VC(i)} + \sum_{j=0}^{m} MCR_{ABR\ VC(j)} \qquad (1)$$

where i and j are indices, n represents the number of non-ABR virtual circuits supported by the device, and m represents the number of ABR virtual circuits supported by
20   the device.

Each device will have a signaling virtual circuit that allows for the connection and disconnection of other virtual circuits. In a preferred embodiment the signaling virtual circuit is an ABR circuit. Alternatively, the signaling
25   channel has a constant data rate established by a CBR virtual circuit, or has a variable date rate established by using a VBR virtual circuit.

The MCR (or PCR) of this signaling virtual circuit will ensure that PCR_{device} never falls to zero, even when no other
30   virtual circuits are connected. This results in the issuance of periodic grants which form the signaling virtual circuit. The exact data rate of the signaling virtual circuit will depend on the application, and extremely low data rates (e.g. b/s) with long times between grants (e.g.

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seconds) will be adequate for some applications, while for other applications high data rates (e.g. 100s of kb/s) with short times (e.g. μs) between grants will be required.

In a preferred embodiment one grant table 700 exists
5 per coaxial drop cable 210, and its contents simply indicate a sequence of device IDs which should, in order, be given grants. The ONU (110) continually progresses through the grant table from beginning to end, generating grants as it does.

10 Downstream and upstream frame structures can be used in a multiple access system such as that illustrated in FIG. 1, with grants being allocated in a downstream frame, and cells being transmitted in an upstream frame. Furthermore, a superframe can be defined as an integer number of frames.

15 The upstream superframe length can be defined as T_{sf_up}, and the downstream superframe length as T_{sf_down}. Suitable values for the superframe lengths are $T_{sf\_up} = 125$ μs and $T_{sf\_down} = 125$ μs. In a preferred embodiment four upstream cells are transmitted every downstream superframe, with each cell

20 corresponding to an upstream frame. In a preferred embodiment the downstream superframe is composed of a single frame. Four grants are transported downstream in a downstream frame and allow specific devices 140 to transmit upstream in the following frame.

25 The number of entries q in the grant table can be calculated as

$$q = p \times k \qquad\qquad (2)$$

where k is an arbitrary constant which defines the granularity of the bandwidth which can be allocated to a

30 particular device 140, and p is the number of upstream cells transmitted during a downstream superframe.

To determine an appropriate value for k it is useful to consider the minimum peak cell rate, PCR_{min}, which can be calculated as

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$$PCR_{min} = \frac{1}{\left(T_{sf\_up} \times k\right)} \quad \left(\frac{cells}{s}\right) \tag{3}$$

The minimum transport rate which results from the minimum peak cell rate can then be calculated as

$$TR_{min} = PCR_{min} \times PL \tag{4}$$

5   where PL is the cell payload in bits.

The variable r can be used to represent the number of entries in the grant table allocated for a specific device, and can be determined as

$$r \geq Int\left\{\frac{PCR_{dev}}{PCR_{min}}\right\} \tag{5}$$

10   where Int represents the integer function which results in the rounding up the value in brackets to the next highest integer value.

In a preferred embodiment four upstream cells are transmitted every 125 µs downstream superframe. The grant

15   table has a depth of $q = 4k$, with the value of PCR_{min} being 8,000/k cells per second, given that T_{sf_up} is equal to 125 µs. In a preferred embodiment the cell payload is equal to 384 bits, which results in a minimum transport rate of $TR_{min} = 3.072/k$ Mb/s.

20   A suitable design choice for k is 128, which results in a minimum transport rate of $TR_{min} = 24$ kb/s, and a grant table with a depth of $q = 512$ entries. Assigning a device the minimum transport (peak cell) rate results in $PCR_{dev} = PCR_{min}$ and $r = 1$, with one entry in the grant table for that device.

25   This corresponds to the transmission of one 384 bit cell from a device 140 every 16 ms.

In a preferred embodiment the device ID in each grant table entry can have 16 possible values:

0 indicating that an upstream cell opportunity can

30   be used on a contention basis by all devices;

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1 to 14 indicating that an upstream cell
opportunity is to be used by the device 1 to 14 as
specifically indicated; and
15 indicating that an upstream cell opportunity is
5   not allocated, and that the upstream cell
opportunity can be used for ABR virtual circuits.
This results in a grant table width, w, of 4 bits.

Based on the value for PCR_{dev} for a given device, the
number of grant table entries, r, required for that device
10   can be calculated. Each of these r entries should have the
device ID (1 to 14) of the corresponding device.

When a new virtual circuit is established between a
device and the ONU, the PCR_{dev} value for that device may
increase. When this occurs r may also increase, and new
15   grant table entries with the corresponding device ID should
be added accordingly (replacing existing entries having a
value of '15' with new entries corresponding to the device
ID).

As shown in FIG. 3, these new entries are determined
20   and are recognized as the desired grant table locations 605.
The ideal locations will be based upon fixed locations (at
regular intervals) in the grant table memory 510, since the
fixed locations at regular intervals result in minimized
CDV.

25   These are the places where grants should occur in order
to eliminate CDV. There may be existing grant table entries
600 in these locations. Grants are placed as close to
these optimum locations as possible by examining the grant
opportunities surrounding the optimal location in ever-
30   increasing intervals. An interval which extends one
location above or below the desired location is considered a
first level search space 620. Alternate search spaces
corresponding to locations further away from the ideal
location can be used. The grants are placed in the first
35   available slot, and the next optimum location is examined.

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When examining nearby opportunities at the edges of the
table, the table is considered circular. The final grant
allocations 610 correspond to the placement of the grants in
such a manner that the CDV is minimized.

5   FIG. 4 illustrates how further improvement can be
obtained by utilizing an offset 630 which results in better
placement of the final grant allocations 610 based on the
existing grant allocations 600 and the desired grant
allocations 605 utilizing the first level search space 620.

10   The C++ algorithm shown in FIG. 6 implements the grant
allocation process illustrated in FIG. 3.

         When an existing virtual circuit between a device and
the ONU is removed, the PCR_{dev} value for that device is
likely to decrease. When this occurs r may also decrease,

15 and an appropriate number of grant table entries with the
corresponding device ID should be removed by changing those
entries to a value of '15'.

         When the grant table has all of the required entries
for each device, such that these grants result in an

20 upstream cell rate for each device which is at least PCR_{dev},
the ONU may be able to provide additional grants in order to
better support ABR virtual circuits. Specifically, for each
unused grant table entry (indicated by a value of '15'), the
ONU can allocate a grant to a device which has ABR cells

25 waiting for transmission.

         In order to provide optimal ABR support, the grants
generated for ABR cells must be dynamically changeable. In
particular, a means is required of altering the generated
grants rapidly in response to knowledge of the ABR cell

30 queue depths in the devices 140. Grants related to CBR and
VBR virtual circuits, and to the ABR MCR requirement are not
altered and remain static in the grant table to provide the
negotiated QoS for each virtual circuit.

FIG. 5 illustrates a method and apparatus for generating ABR grants based on available grant table entries, and the requirement of a device 140 to transmit ABR cells. In a preferred embodiment, the grant table 700 and

5 queue tables 730 are located in ONU 110. The method consists of a having a counter 710 which cycles through the grant table 700 illustrated in FIG. 2. The counter produces the grant table address GTADDR 701 which results in grant table data GTDATA 703 being read out. The GTDATA data 703 of

10 FIG. 5 corresponds to the memory data outputs 515 of grant table 700 illustrated in FIG. 2. This data goes to a multiplexor 725, and a ABR grant generator 720.

Referring to FIG. 5, each device 140 reports on the number of ABR cells it has for transmission, this

15 information being stored in a queue table 730. When the ABR grant generator 720 receives a grant which indicates that no device will transmit cells (corresponding to value '15'), it inspects the queue table 730 by sending a device ID on the queue table address, QTADDR line 707 and receiving a number

20 on the queue table data, QTDATA line 709 which corresponds to the number of ABR cells that device 140 has in its ABR queue to transmit. If the device has ABR cells in this queue, the ABR grant generator 720 asserts the OKAY signal 705 which causes the multiplexor 725 to transmit the device

25 ID on its output as a GRANT VALUE 711. In the event that the queue table 730 indicates that that particular device 140 does not have ABR cells in its ABR queue, it goes to the next device address to determine if that device has cells in its queue.

30 A method which describes this process, and which is equivalent in function to the circuit shown in FIG. 5, is shown in FIG. 7. It makes use of queue depth information from a single ABR queue in each device. Each device 140 reports on the status of an ABR queue, with the queue number

35 of that queue constant throughout all devices 140. The ABR queue information carried in every upstream cell is used to

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update queue table 730 in the ONU. This table has an entry
for each device ID which indicates the number of ABR cells
awaiting transport from that device. In a preferred
embodiment, the queue table 730 has a width of 4 bits and a
5   depth of 14. In an alternate embodiment multiple queues can
exist in each device with corresponding queue tables for
each device

     The variable *Xon* in the method shown in Table II of
FIG. 7 refers to a signal generated at a higher level which
10   indicates whether or not ABR grants should be generated.
Setting *Xon* equal to 'false' will prevent any ABR grants
from being issued. The utility of having an *Xon* variable
with 'true' and 'false' settings is that if there is not
sufficient bandwidth in another part of the access system
15   for ABR cells, setting *Xon* equal to 'false' will prevent
devices 140 from transmitting ABR cells and prevent overflow
of memories or First-In-First-Out (FIFO) structures in the
system.

     In a preferred embodiment an ABR queue is present in
20   HDT 100, which receives cells transmitted from ONU 110 over
optical fiber 200. When the ABR queue in HDT 100 is full,
HDT 100 can set the *Xon* variable to 'false' which will
prevent ABR grants from being issued to devices 140, as
illustrated in FIG. 7.

25   Because there is a propagation delay between HDT 100
and ONU 110, there is a delay between when HDT 100 indicates
that its ABR queue is full and when the last ABR cell from
an ONU 110 arrives at HDT 100. This delay is equal to the
round trip transport time between HDT 100 and the ONU 110
30   which is furthest away. The delay can result in an overflow
of the HDT ABR queue since additional cells can arrive at
HDT 100 even though the *Xon* signal has been set equal to
'false' and transmitted to the ONU 110.

In a preferred embodiment the delay can be accommodated by dimensioning the ABR queue size Q_{HDT} in HDT 100 to be equal to

$$Q_{HDT} = 2 \times c_{transit} \times SMR \qquad (6)$$

5 where $c_{transit}$ is the maximum number of cells which can simultaneously exist in transit on the longest link between HDT 100 and ONU 110, and SMR is the statistical multiplexing region. The statistical multiplexing region should be large enough to account for the normal variations in the number of 10 queued cells. If the statistical multiplexing region is too small, the ABR upstream flow from the ONU 110 will constantly be turned on and off, even during normal traffic conditions.

An application of the invention is the transmission of 15 data from a device such as a computer located in residence 250 and connected to device 140 to ONU physical layer transceiver 120 located in ONU 110. The computer may be allocated bandwidth using an ABR mechanism in order to allow it to transmit a file to ONU 110 and on to HDT 100 for 20 transmission to another computer which is connected to HDT 100 via a Public Switched Telecommunications Network (PSTN) or a private telecommunications network. The device 140 connected to the computer can be allocated grants using one of the embodiments of the present invention, such that the 25 bandwidth on the subscriber coaxial network is effectively used. The effective use of the bandwidth becomes more important if there are other devices 140 in the same residence 250 which are utilizing CBR or VBR virtual circuits for applications such as telephony or video. In 30 this case allowing the computer to utilize upstream cells not required for CBR or VBR services permits all devices in the home to be used simultaneously and does not waste cells by establishing a CBR or VBR virtual circuit for the computer file transfer when an ABR virtual circuit is 35 adequate.

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Although this invention has been illustrated by
reference to specific embodiments, it will be apparent to
those skilled in the art that various changes and
modifications may be made which clearly fall within the
5   scope of the invention. The invention is intended to be
protected broadly within the spirit and scope of the
appended claims.

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Claims

What is claimed is:

1. In a cell based communications network having a physical layer where said physical layer has a transceiver of a first type connected to at least one transceiver of a second type, a method of allocating bandwidth on said physical layer, said method comprising the steps of:

    a) constructing a grant table in said transceiver of a first type wherein said grant table contains grants corresponding to cell opportunities for transmission of cells from said transceiver of a second type to said transceiver of a first type over said physical layer;

    b) determining the number of said grants required in said grant table to allow said transceiver to transmit cells at a specified rate of transmission;

    c) generating multiple grants in said grant table wherein said multiple grants have addresses associated with said transceiver of a second type; and

    d) optimizing locations of said multiple grants in said grant table to minimize variations in the spacing of said multiple grants.

2. The method described in claim 1 further characterized in that said optimization of said locations of said multiple grants comprises the steps of;

    e) determining optimum locations for said multiple grants to realize said specified rate of transmission;

    f) examining said grant table to determine if grants exist in said optimum locations;

    g) determining first possible locations for said multiple grants;

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h) offsetting said optimum locations by an integer number of grant locations;

i) determining alternate possible locations for said multiple grants; and

j) selecting final grant locations from said first possible locations and said alternate possible locations.

3. In a cell based communications network having a physical layer where said physical layer has a transceiver of a first type connected to at least one transceiver of a second type, a method of allocating bandwidth on said physical layer, said method comprising the steps of:

a) constructing a grant table in said transceiver of a first type wherein said grant table contains grants corresponding to cell opportunities for transmission of cells from said transceiver of a second type;

b) transmitting a data field from said transceiver of a second type to said transceiver of a first type wherein said data field represents the number of cells stored in said transceiver of a second type awaiting transmission to said transceiver of a first type on an available bit rate basis;

c) constructing a queue table in said transceiver of a first type wherein said queue table indicates the number of cells requiring transmission from said transceiver of a second type to said transceiver of a first type;

d) determining whether said grant table has an entry which indicates that a cell opportunity is unused;

e) determining whether said queue table in said transceiver of a first type has at least one entry indicating that at least one cell is

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awaiting transmission from said transceiver of a
second type; and

f) generating   a   grant   having   an   address
corresponding to an address of said transceiver
of a second type.

4. The method described in claim 3 further characterized in
that a plurality of transceivers of a second type transmit
data fields wherein said data fields represent the number of
cells stored in a representative transceiver of a second
type awaiting transmission to said transceiver of a first
type on an available bit rate basis, said method further
comprising the step of:

g) constructing a plurality of queue tables in
said transceiver of a first type wherein said
plurality of queue tables indicate the number of
cells requiring transmission from said plurality
of transceivers of a second type.

5. The method described in claim 4 further comprising the
step of:

g) when the queue table corresponding to a first
respective transceiver of a second type does not
have an entry indicating that at least one cell
is   awaiting   transmission   from   said   first
respective   transceiver   of   a   second   type,
determining   whether   the   queue   table
corresponding to a second respective transceiver
of a second type has an entry indicating that at
least on cell is awaiting transmission from said
second respective transceiver of a second type.

6. The method described in claim 5 further comprising the
step of:

h) cycling through the queue tables of each of
said plurality of transceivers of a second type
in a sequential manner to determine which

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transceivers of a second type has at least one
entry indicating that at least one cell is
awaiting transmission from said transceiver of a
second type.

7. In a cell based communications network having a physical
layer and where said physical layer has a master transceiver
containing an available bit rate cell queue and at least one
transceiver of a first type connected to at least one
transceiver of a second type, a method of preventing
available bit rate cell queue overflow at said master
transceiver, said method comprising the steps of:

    a) determining when said available bit rate cell
       queue at said master transceiver has minimal
       additional capacity; and

    b) transmitting a signal from said master
       transceiver to said transceiver of a first type
       wherein said signal indicates that no cells
       should be transmitted on an available bit rate
       basis.

8. The method described in claim 7 wherein said available
bit rate cell queue at said master transceiver has
sufficient depth such that cells in transit on said physical
layer between said transceiver of a first type and said
master transceiver can be accommodated without causing an
overflow of cells.

9. In a cell based communications network having a physical
layer where said physical layer has a transceiver of a first
type connected to at least one transceiver of a second type,
an apparatus for allocating bandwidth on said physical
layer, said apparatus comprising:

    a) means for constructing a grant table in said
       transceiver of a first type wherein said grant
       table contains grants corresponding to cell
       opportunities for transmission of cells from

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said transceiver of a second type to said
transceiver of a first type over said physical
layer;

b) means for determining the number of said grants
required in said grant table to allow said
transceiver to transmit cells at a specified
rate of transmission;

c) means for generating multiple grants in said
grant table wherein said multiple grants have
addresses associated with said transceiver of a
second type; and

d) means for optimizing locations of said multiple
grants in said grant table to minimize
variations in the spacing of said multiple
grants.

10.   The apparatus described in claim 9 further
characterized in that said means for optimization of said
locations of said multiple grants comprises;

e) means for determining optimum locations for said
multiple grants to realize said specified rate
of transmission;

f) means for examining said grant table to
determine if grants exist in said optimum
locations;

g) means for determining first possible locations
for said multiple grants;

h) means for offsetting said optimum locations by
an integer number of grant locations;

i) means for determining alternate possible
locations for said multiple grants; and

j) means for selecting final grant locations from
said first possible locations and said alternate
possible locations.

11.   In a cell based communications network having a
physical layer where said physical layer has a transceiver

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of a first type connected to at least one transceiver of a second type, an apparatus for allocating bandwidth on said physical layer, said apparatus comprising:

a) means for constructing a grant table in said transceiver of a first type wherein said grant table contains grants corresponding to cell opportunities for transmission of cells from said transceiver of a second type;

b) means for transmitting a data field from said transceiver of a second type to said transceiver of a first type wherein said data field represents the number of cells stored in said transceiver of a second type awaiting transmission to said transceiver of a first type on an available bit rate basis;

c) means for constructing a queue table in said transceiver of a first type wherein said queue table indicates the number of cells requiring transmission from said transceiver of a second type to said transceiver of a first type;

d) means for determining whether said grant table has an entry which indicates that a cell opportunity is unused;

e) means for determining whether said queue table in said transceiver of a first type has at least one entry indicating that at least one cell is awaiting transmission from said transceiver of a second type; and

f) means for generating a grant having an address corresponding to an address of said transceiver of a second type.

12. The apparatus described in claim 11 further characterized in that a plurality of transceivers of a second type transmit data fields wherein said data fields represent the number of cells stored in a representative transceiver of a second type awaiting transmission to said

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transceiver of a first type on an available bit rate basis, said apparatus further comprising:

g) means for constructing a plurality of queue tables in said transceiver of a first type wherein said plurality of queue tables indicate the number of cells requiring transmission from said plurality of transceivers of a second type.

13. The apparatus described in claim 12 further comprising:

g) means for determining when the queue table corresponding to a first respective transceiver of a second type does not have an entry indicating that at least one cell is awaiting transmission from said first respective transceiver of a second type; and

h) means for determining whether the queue table corresponding to a second respective transceiver of a second type has an entry indicating that at least on cell is awaiting transmission from said second respective transceiver of a second type.

14. The apparatus described in claim 13 further comprising:

i) means for cycling through the queue tables of each of said plurality of transceivers of a second type in a sequential manner to determine which transceivers of a second type has at least one entry indicating that at least one cell is awaiting transmission from said transceiver of a second type.

15. In a cell based communications network having a physical layer and where said physical layer has a master transceiver containing an available bit rate cell queue and at least one transceiver of a first type connected to at least one transceiver of a second type, an apparatus for preventing available bit rate cell queue overflow at said master transceiver, said apparatus comprising:

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a) means for determining when said available bit
   rate cell queue at said master transceiver has
   minimal additional capacity; and

b) means for transmitting a signal from said master
   transceiver to said transceiver of a first type
   wherein said signal indicates that no cells
   should be transmitted on an available bit rate
   basis.

16. The apparatus described in claim 15 wherein said
available bit rate cell queue at said master transceiver has
sufficient depth such that cells in transit on said physical
layer between said transceiver of a first type and said
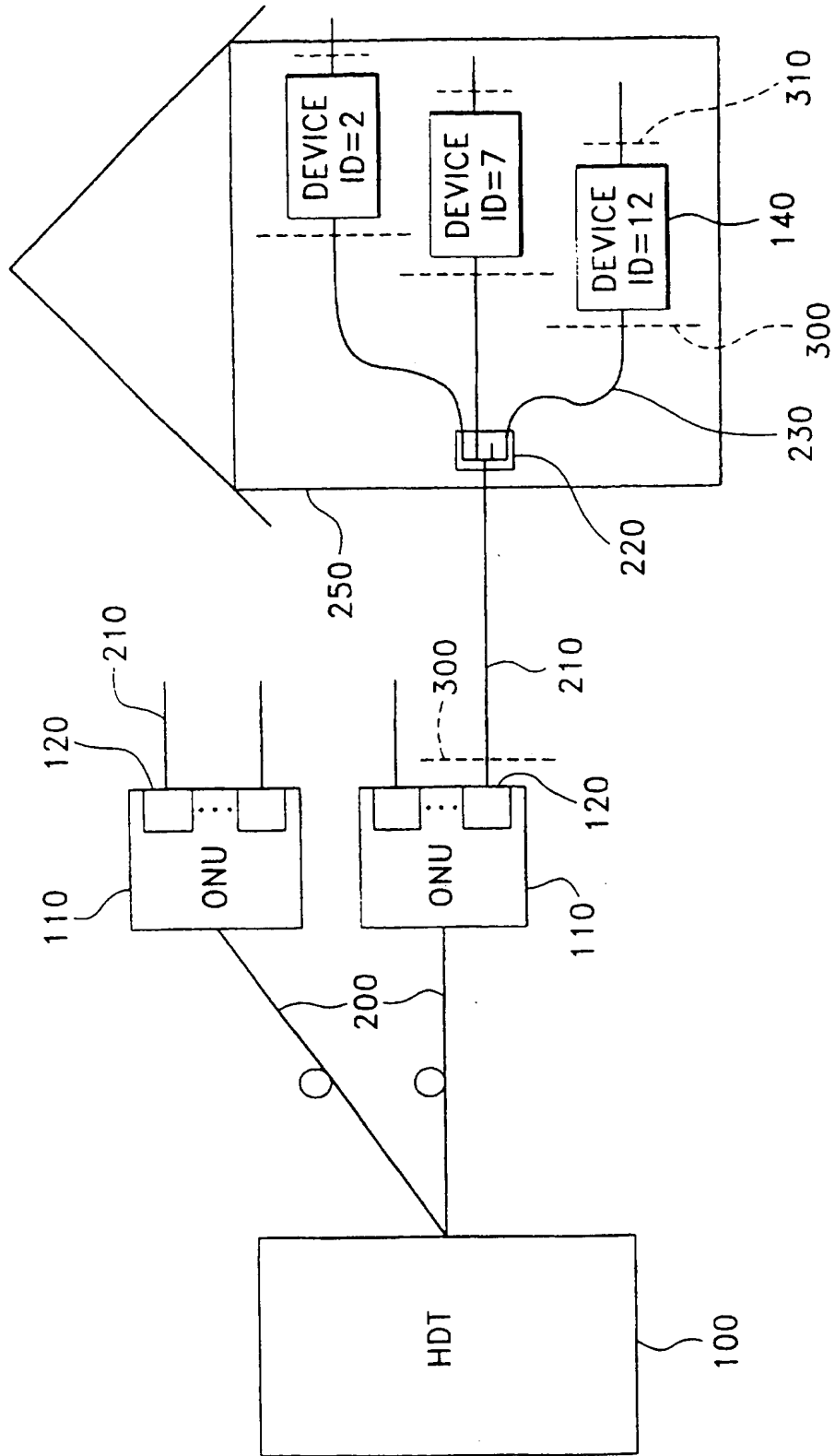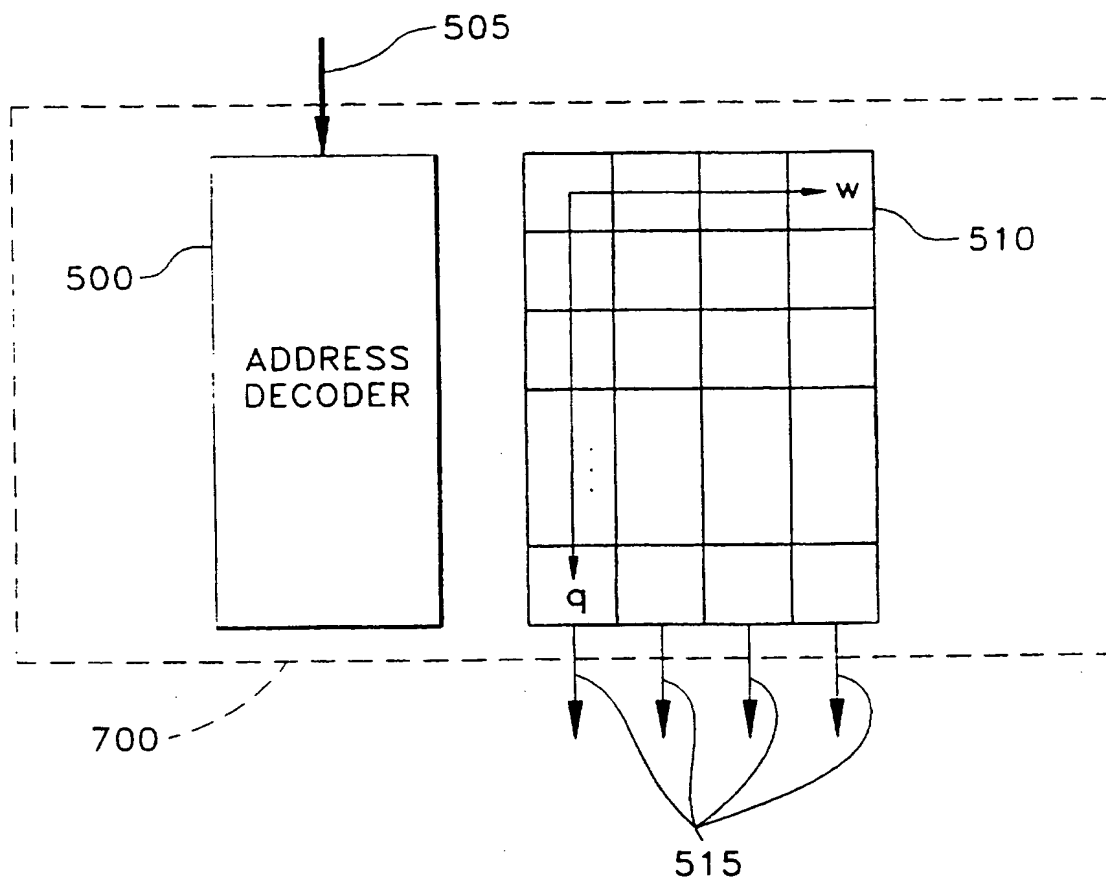master transceiver can be accommodated without causing an
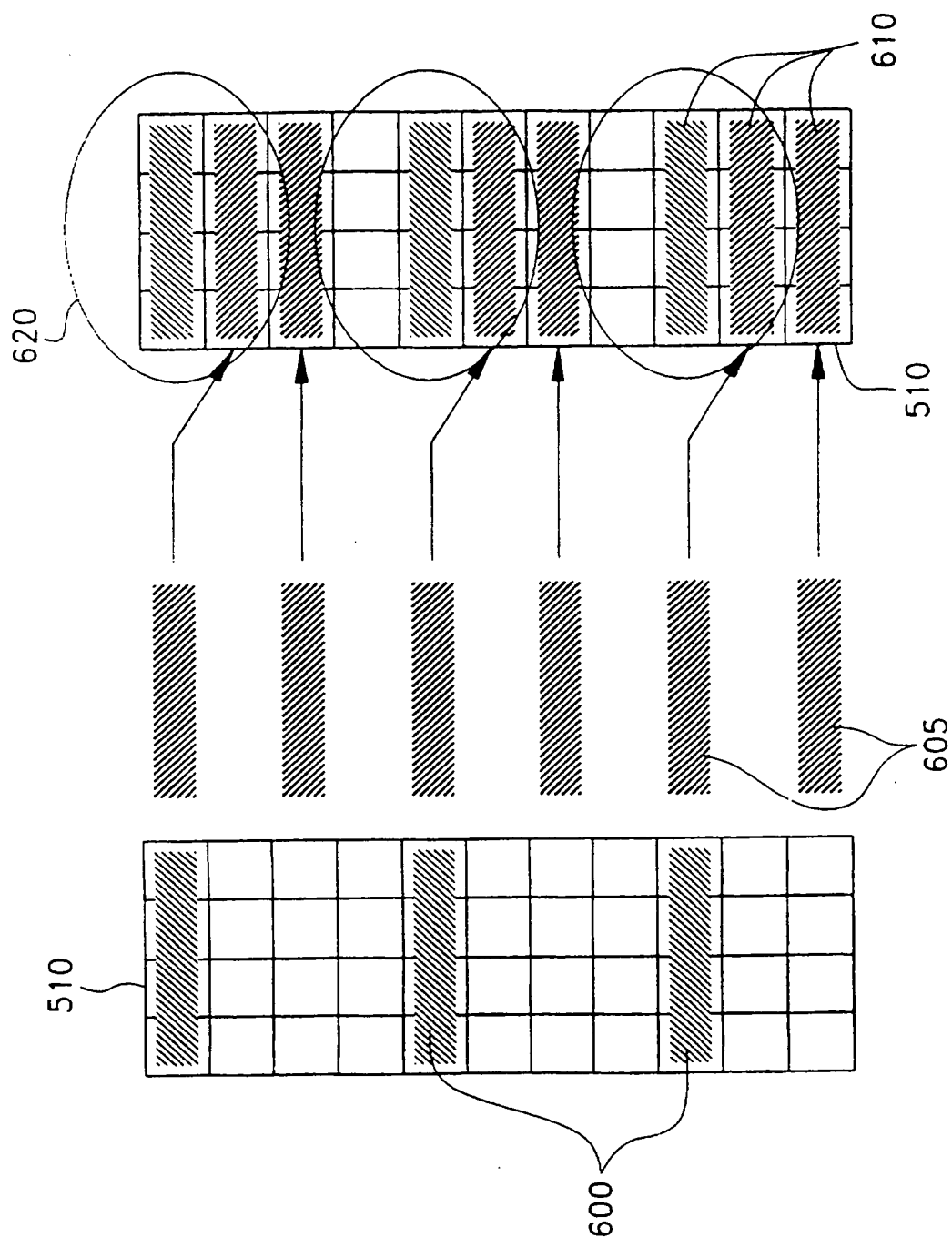overflow of cells.

FIG. 1

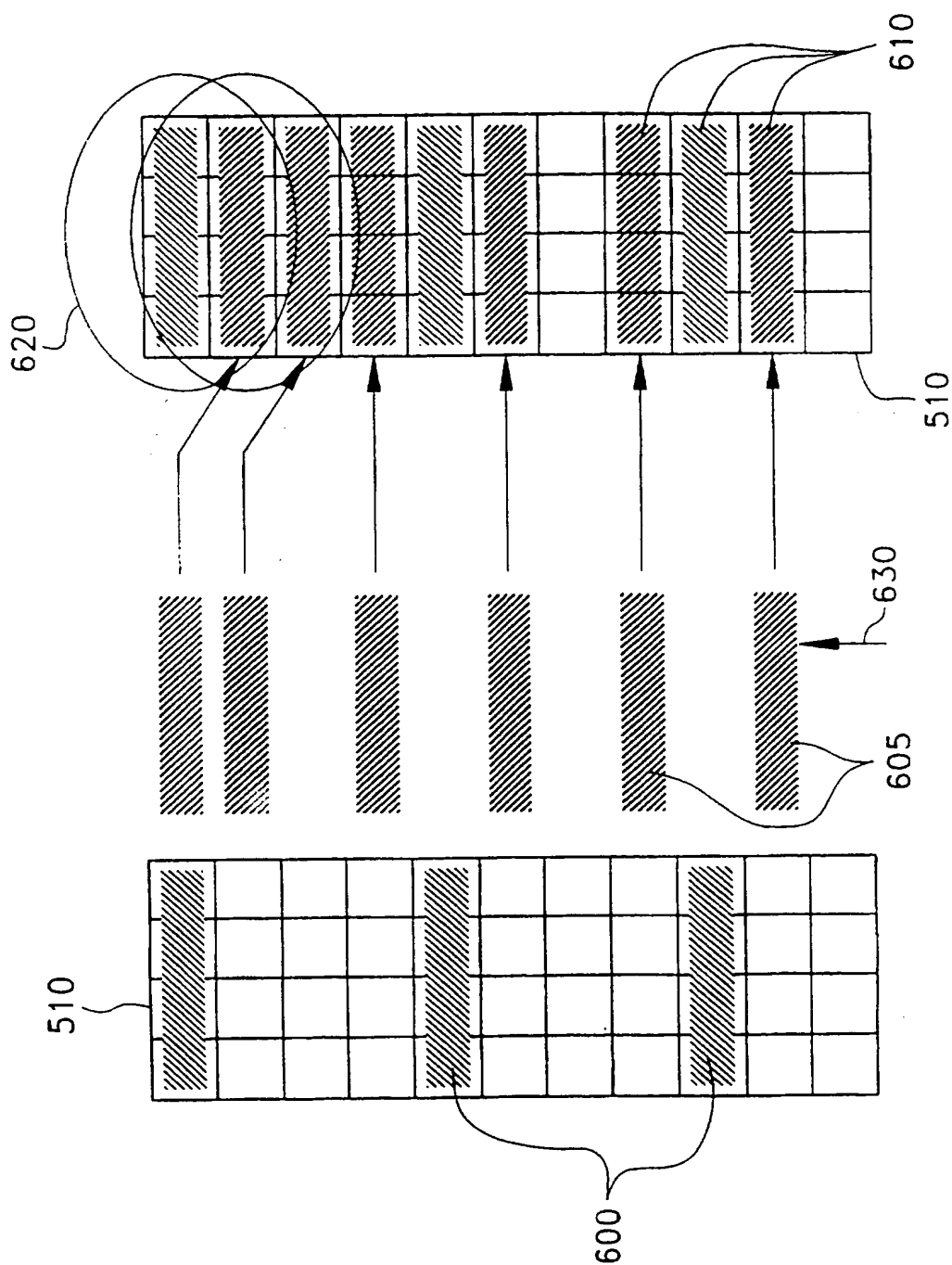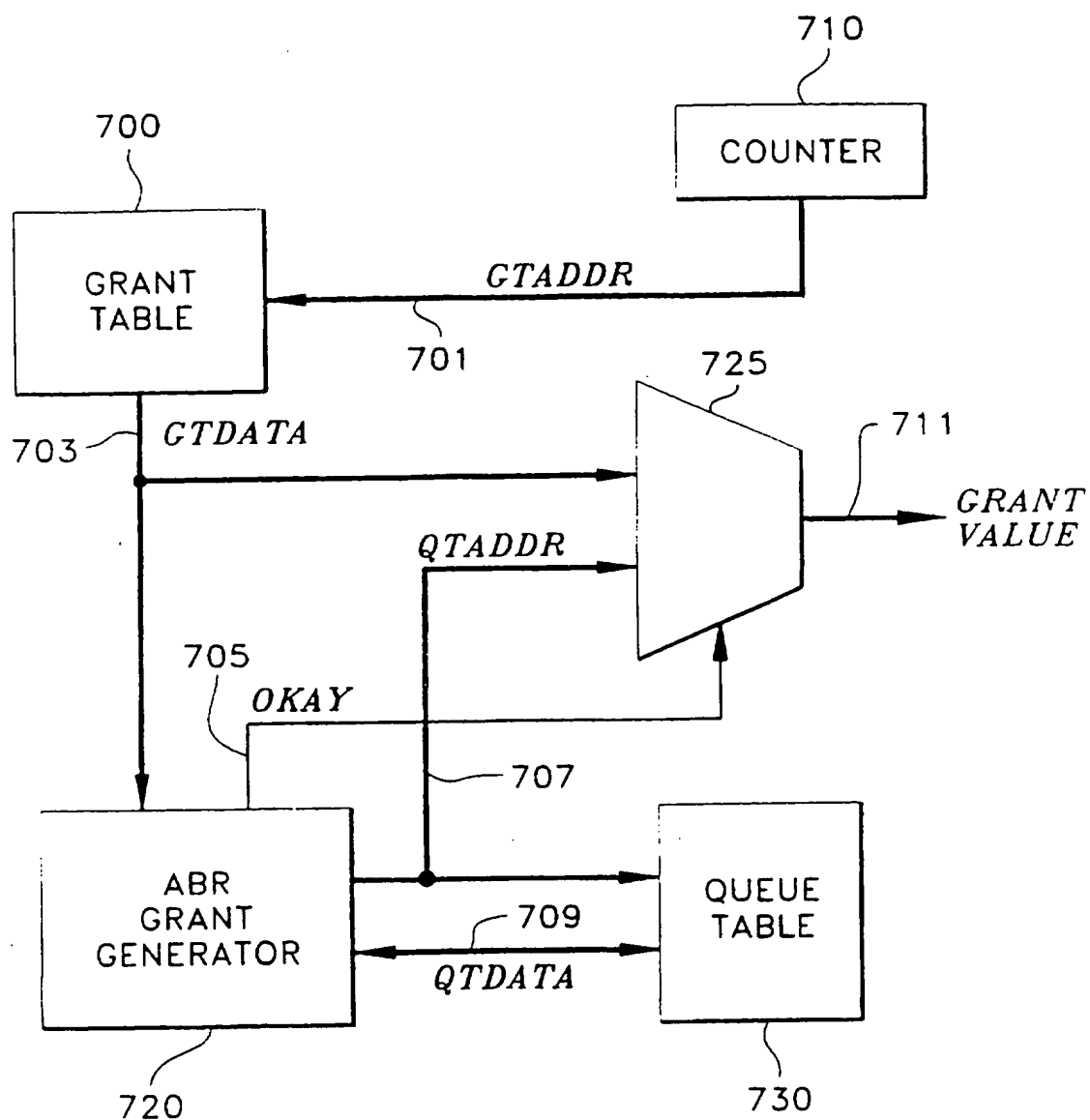FIG. 2

FIG. 3

FIG. 4

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FIG. 5

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```
for(i = 0; i < newGrants; i++) {

    int optimumLocation = round(i * 4 * k / n);   /* optimum location */

    int dither = 0;
    int ifound = 0;

    do {
        int hival = (optimumLocation + dither) % GRANT_TABLE_SIZE;
        int loval = (GRANT_TABLE_SIZE
                        + optimumLocation
                        - dither) % GRANT_TABLE_SIZE;

        if (grantTable[hival] == 15) {              /* check ahead */
            grantTable[hival] = deviceID;
            ifound = 1;
            continue ;    /* skip to end of do */
        };

        if (grantTable[loval] == 15) {          /* check behind */
            grantTable[loval] = deviceID;
            ifound = 1;
            continue ;    /* skip to end of do */
        };

        dither++;

    } while (ifound == 0 && dither <= round(4 * k / n));

};
```

FIG. 6

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```
index = 0
last = 1
endless loop:
grant = grantTable[index]                              /* read grant from grant table */
if (Xon = "true" and grant = 15):                      /* if no device is being issued a grant */
    next = last
    do:
        next = next + 1                                /* progress through devices */
        if (next = 15) next = 1                         /* last device is device 14 */
        if (queueTable[next] ≠ 0):                     /* if there is data in that device queue, */
            grant = last = next                        /* issue a grant to that device */
            queueTable[next] = queueTable[next] - 1    /* decrement queue table */
    while (next ≠ last)
index = index + 1
if (index = 4k) index = 0
```

/* 14 devices in residence to be addressed */

FIG. 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04Q 1/20, H04J 3/14
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/229, 230, 231, 236, 395, 412, 413, 415, 420, 462; 455/4.2, 5.1; 348/12, 13

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US, A, 5,493,566 (LJUNGBERG ET AL) 20 February 1996, col. 4, line 58, to col. 5, line 22 and col. 6, lines 23-67.	7 and 8
A,P	US, A, 5,521,923 (WILLMANN ET AL) 28 May 1996, col. 4-5.	7 and 8

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date		
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 JANUARY 1997	**31 JAN 1997**

Name and mailing address of the ISA/US	Authorized officer
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Form PCT/ISA/210 (second sheet)(July 1992)*

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

370/229, 230, 231, 236, 395, 412, 413, 415, 420, 462; 455/4.2, 5.1; 348/12, 13